Bridge Management System: Computer-Aided Planning Decision System for Polish Road Administration

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A computer-aided system for the management of bridge structures in the Polish Road Administration is described. The Polish Bridge Management System (BMS), which is still being developed, is grouped in modules containing optimization procedures that support maintenance and management problems. Some of the procedures are based on the method of taxonomic investigation as being optimal for determining the priority for bridges qualified for rehabilitation that forms the basis for a yearly plan at the regional level.

The bridge management process, generally speaking, consists in the selection of an optimal strategy for allocation of budgetary means for the maintenance of bridges on the basis of information collected about their condition. To manage bridges one needs both specialized administration and a practical instrument facilitating data processing and supporting the decision-making process.

The traditional method of bridge management (reporting), which is still in force, produced a vast set of data without using it effectively. The processing of data via reporting made it impossible to utilize fully the collected data base for decision making. The fact that there was no efficient and nationally uniform system of data processing made it impossible to objectively appraise the condition of bridge management in the particular administrative regions so that both financial and material expenditures on bridge maintenance would be used effectively (*1*).

Therefore, a computer-aided bridge management system, referred to as the Bridge Management System (BMS), was designed. The BMS will serve as a tool in managing bridges for Polish public roads.

General Description

The BMS must be compatible with the road management structure. In Poland there is a central road administration that operates on three levels (2):

- Country: general directorate of public roads (GDDP),
- Regional: regional directorates of public roads (DODP), and
- Basic: road management units (ZD).

The Polish BMS is equipped with numerous procedures to aid in planning decisions at each of the three levels of management. Generally, the system consists of the basic module, Inventory (EGM); the program Bridge Data Books (KPOM); and modules Current Maintenance (BUM), Major Repair (RKOM), and so on, which together serve the selected options of the planning function. In addition, the system is aided by the program Central Inventory of Great Bridges (CEDOM), which is a computer inventory of a selected group of large bridges (Figure 1).

The basic task of the BMS is to systematically generate information about the condition of bridges in management units, regions, and countrywide and to allocate funds for maintenance and repairs to regions, management units, and objects. All data, such as inventory and bridge condition, are registered and verified at the lowest level and transmitted to the higher levels.

The particular modules and programs of the BMS can be grouped because, besides collecting or processing appropriate information, they serve the basic data bases of the system that are utilized in the computer-aided process of making planning decisions.

Location Data Base: Uniform Inventory Number

An indispensable condition for the function of the system is unequivocal location of bridges on roads and concurrence with road systems. In its original version, the BMS was inseparably configured with the Roads Description Reference System (NET) in which bridges were identified using the code BPS (a description of the spatial location of a bridge on a road management–specific system of coordinates).

A drawback to this solution, apart from the fact that the BMS could not be installed and implemented without the functioning system NET, was the location of bridges by means of the code BPS. Because implementation of a new reference system based on geographical coordinates had begun, a decision was made to make the entire BMS independent of an arbitrary system of road description in this country.

To achieve this, a general assumption was made that each bridge would be identified by a unique, positive, eight-digit integer called a Uniform Inventory Number (JNI) that would not contain any information about location. The method adopted would allow the whole BMS system to be independent of any administrative-organizational changes, and because of the uniform countrywide method of coding, it would be possible to combine the existing location data base (collected in the module Inventory) with any reference system describing the road net (*3,4*).

Currently, each bridge in the BMS can be located by means of the JNI, geographical coordinates, and the number and kilometers of the road. In future, each

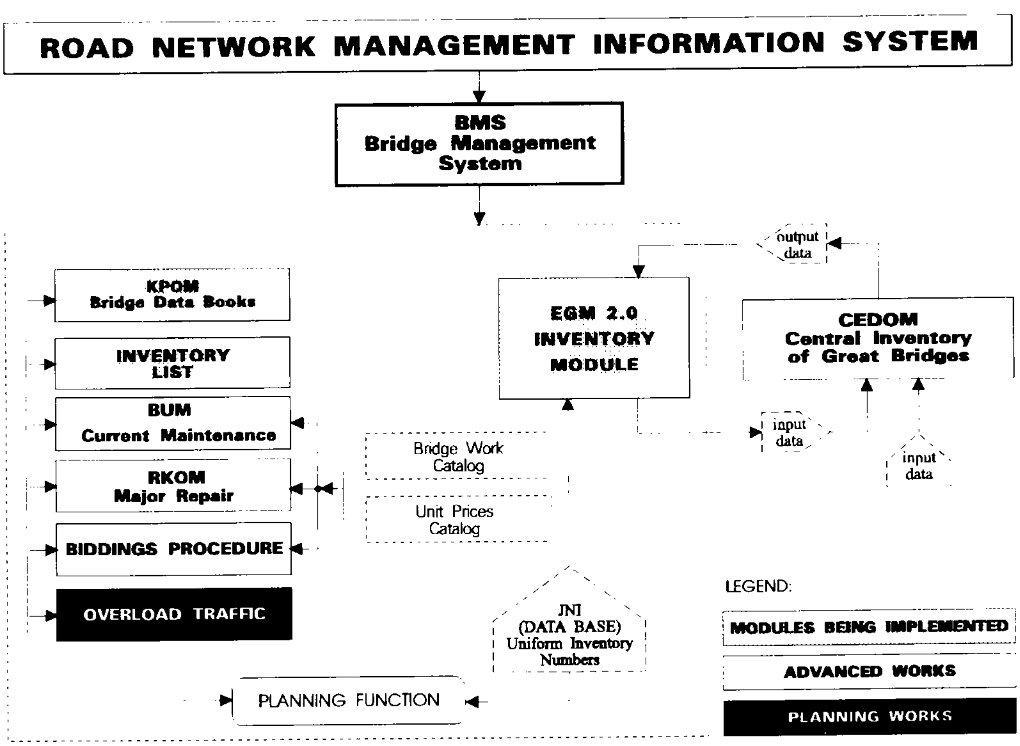

FIGURE 1 Flowchart of Bridge Management System in Poland.

bridge will be assigned through its JNI to a concrete section of a road (the reference section) so that close communication between the BMS and the road reference system will be ensured.

Inventory Data Base

The BMS software uses the same inventory data base made up of the module EGM and the auxiliary programs KPOM, Inventory List, and CEDOM. Module EGM is the basic component of the BMS and collects location, inventory, technical, and historical data describing individual objects in detail (e.g., bridges, footbridges, floating bridges, missing bridges, ferry crossings, tunnels, underpasses, and culverts). This module in the Polish BMS is a major bridge data base and functions from the basic level (the ZDs) through the regional levels (the DODPs) to the country level (GDDP). The available set of data that describe bridges is formed at the basic level and then transmitted to the higher levels of management (*5*).

Such data as, for example, the length and width of a bridge, the kind of material, and the technical condition are automatically drawn from the existing inventory data base by program KPOM, which generates all the statistical data used in planning procedures. The program also divides the groups statistical data at each of the management levels (*3*). The program Inventory List, which on the basis of the necessary data drawn from the inventory data base of module EGM generates exclusively reports mandated by DP.A.-16, operates on the same principle (*3*).

CEDOM's special task is to supplement the inventory data base. This program serves a select group of large bridges on bigger rivers in Poland and allows one to prepare several nonstandard reports about these bridges. It is directly connected to the module Inventory by the JNI. In addition, because of its special structure, CEDOM supplies the Bridge Division of the GDDP, bypassing the regional level, with a full range of countrywide inventory information on large bridges (*6*).

Bridge Work Data Base

Another essential data base in the Polish BMS is a bridge work data base, which is a list of work and costs associated with each bridge in a given year. It contains the object's JNI, the date the work is completed, a list of work, and the cost (*7*).

The basic component of the bridge work data base is the Bridge Work Catalog, which has a special structure and contains a list of all types of bridge work, each coded with three two-digit numbers. The first number is the type of work, the second refers to the list of this type of work, and the third divides this work into unit sizes and is connected with the Unit Prices Catalog.

All the work done (codes and sizes) and the associated expenditures are registered for each bridge by means of the appropriate JNI, and in the future, the BMS will be able to describe the relationship between the technical condition of a bridge and the expenditures, which is very important for long-term planning.

A source of the data for the bridge work data base is the program Biddings Procedure, which works directly with the program that serves the bridge work data base. Other data, for example, work done with own funds, will be input directly.

Bridge Ratings Data Base

In the Polish BMS, all information on the technical condition of bridges comes from basic and detailed inspections (*8*). Therefore one of the first elements needed for the computer-aided planning decision system was a basic inspection data form from which a catalog of typical bridge element damages and principles of bridge technical condition rating could be compiled (*9*).

The software that is currently used as a base for the ratings is the program Basic Inspection Data Form Editor (KPP), which as one of the procedures of module BUM describes in computer terms the basic inspection. Program KPP operates jointly with the Inventory data base because some parts of this program provide information on the location and structure of bridges. These data are automatically collected by a computer from module EGM and entered into program KPP installed in a bridge inspector's notebook.

During a bridge inspection, the inspector must describe damage to no fewer than 11 elements and rate each of them using a scale from 0 to 5. Codes of damages are included in this program. A list of element and material damages forms the second part of program KPP.

The overall rating of an object is computed as value S using the following formula:

$$S = \min\left[\frac{1}{n}\sum_{i=1}^{n} S_i,\ S_7,\ S_8,\ \frac{1}{2}(S_{12} + S_{15})\right] \qquad (1)$$

where

S_7, S_8 = beam and deck rating,
S_{12}, S_{15} = piers and abutments rating, and
S_i = all elements rating.

S_i is the lowest from the mean ratings of all the elements, the beams, the deck, and the supports.

The next part of program KPP calculates the price of maintenance or repair of the bridge. The task of a bridge inspector is to determine the amount of damage and the kind of bridge work to be done on each element according to the Bridge Work Catalog and the Unit Prices Catalog. The list of the work is edited on the notebook's monitor. The inspector can automatically choose appropriate work for each element and the computer will calculate the costs of repair or maintenance.

Another part of program KPP is associated with the inspector's decisions about work priority made using the rating scale *A*, 1, 2, 3 (*A* stands for the failure condition of an element). A list of bridge work with priority ratings, costs of repair, and a bridge condition average constitutes the basis for short-term planning at the regional level.

All damage to elements is grouped by the program Basic Inspection Data Form Analyzer (AKPP) and forms bridge condition statistics such as the frequency and the kind of material and element damage (*3*).

Program Bidding Procedure: Data Base of Contracting Companies

The Bidding Procedure program was designed to handle awarding of bids for the construction, maintenance, and repair of bridges at the regional or unit level. The program facilitates the preparation of bids by the regional road administration and monitors the awarding of contracts and their realization.

One of the options of this program allows the recording of unit prices from all regional bids, which constitute the basis for unit prices for bridge work for the next year, including unit prices for the whole country. A record of unit prices makes it possible to predict growth rate, which makes these data very important for long-term planning.

Regional directorates hold several rounds of bidding and have the same number of committees. The whole process is secret and only a particular committee knows the password for a particular bid. Information about the winners of awards is released after public announcement of the bidding results.

In addition, a data base of contracting companies was created in the BMS (in the base of program Bidding Procedures). It gathers information about all the companies that take part in various rounds of bid in which each company can be identified in a simple way by its REGON code (*7*).

Overload Traffic Data Base

The Overload Traffic data base stores information on overload traffic. The source of data acquisition for this base is the module Overload Traffic linked with module EGM since the latter contains all the data on bridge technical condition, load capacity, clearance, and so on. The module collects the following data: heavy-vehicle weight, pressure on drive axles, number of axles, and distance.

One procedure selects the shortest route and another one checks the passage over the bridges on this route. The main criterion is a bridge condition rating of more than 3 for the beams, the deck, the piers, and the abutments.

The Overload Traffic module incorporates a registering process that makes it possible to monitor the number of all overload vehicles yearly on every bridge and the detection of objects especially exposed to degradation. These factors are particularly important for long-term planning (*7*).

Planning Functions in Polish BMS

The planning of maintenance work, both current maintenance and repair, is based mainly on results of basic and detailed inspections; thus, input data for planning are already available to a large degree in the system as presented above.

Generally speaking, planning functions in the computer-aided BMS are to ensure a uniform standard of maintenance and technical condition for bridges in the whole country and rational spending of central budget funds (*10*). In the Polish BMS, these functions are perfomed by the Current Maintenance (BUM) and Major Repair (RKOM) modules.

The GDDP divides expenditures among 17 regional directorates on the basis of collected data on the condition and the number of bridges administered by the particular regions. The calculated replacement values for all bridges, their average rating of technical condition for a given region (collected from program KPP), and statistical data on, for example, the overall area of bridges in the particular regions (contained in the KPOM program) provide a basis for the allocation of funds.

Assuming a desired average level of bridge condition in this country, the necessary amount of expenditure can be determined or, vice versa, knowing the expenditures allocated from the central budget, the effects in the form of higher bridge condition ratings can be estimated. Following this method, a clear-cut mechanism for controlling the relationships between expenditures and bridge condition at the central level of management can be obtained (*11*).

Module BUM at the central level distributes the budget for current maintenance and rehabilitation of bridges among regional directorates and allocates funds for concrete modernization and investment tasks.

The purpose of module BUM at the regional level is to match the range and the scope of work in program KPP with a Bridge Work Catalog and a Unit Prices Catalog to determine the amount of expenditure on current bridge maintenance and to allot work within the rehabilitation range. In this way, the regional level has full information about repair needs.

Module RKOM, in turn, operating at the regional level, compiles a list of rehabilitation needs, calculates the capital costs of repairs, and checks if it may be necessary to modernize a bridge. The list of repair needs for rehabilitation at the regional level is then ranked by the taxonomic method. This classification method together with an efficient system of determining the economic effectiveness of ventures gives the road administration of the regional level an objective apparatus for drawing up a yearly plan of maintenance (*12*).

A bridge modernization plan is a different process. The factor that decides whether modernization is necessary is the exceedance of functional life (insufficient load capacity, lack of clearance), economic life (repair costs exceeding the value determined relative to the replacement costs), or service life (the bridge receives a critically low rating) or the crossing is temporary, so the bridges that have been accepted for modernization form an input basis for a modernization plan.

For all bridge modernization work an internal return rate (IRR) must be calculated. At the national level, funds for bridges are allocated on the basis of which IRR is the highest.

Analysis of Arguments for Repair and Their Evaluation

Repair is based on urgency of the features that need repair. Making a decision about repair is determined by a series of circumstances and events. Therefore, the decision space around each bridge can be described by a set of arguments that, by their description, reveal the importance of these features. An analysis of the arguments, and not personal preference, serves as the basis for a correctly constructed work specification. A certain range of work—the so-called routine current maintenance work—is carried out on bridges and is not subject to ranking by urgency.

The following groups of arguments and diagnostic features can be distinguished (dominant features are underscored):

Group of Arguments	*Diagnostic Features*
Economic	Capital costs, users' costs, available funds, comparison with cost of building new object
Technical	<u>Rating of object's condition</u>, service character
Durability	<u>Estimated percentage of wear and evaluation of degree of bridge's wear</u>
Transportation	<u>Road class</u>, traffic volume, traffic level, defense considerations, fire access road, bridge on border crossing road, international agreements imposed on road's function
Work urgency	Breakdown mode, work under way
Hindrances	Technical, technological

The above groups, taking into account the dominant features, constitute the basis for a description of bridges; by assigning numerical values to the ratings of the arguments, they become arguments of a mathematical method that orders a list of bridges according to the urgency of repair work.

For the evaluation of bridges, the above groups of arguments have been correlated and a grading scale has been assigned to the dominant features. Numerical values have been adopted in reference to the six-grade scale used in the Polish BMS for evaluating the technical condition of bridges (0 = failure condition, 5 = excellent condition). The method described assumes the following diagnostic features as dominant: rating of object's technical condition, road class, and evaluation of durability (degree of wear); it also analyzes the hindrances and the work urgency (*13*).

Bridge Condition

The grading scale is from 0 to 5, in which a grade is generated from program KPP (see the description of the bridge ratings data base).

Class of Road

A six-grade scale is imposed to divide Polish roads according to categories and their corresponding weights:

Description	*Rating*
Roads with one-digit designations	0
Roads with two-digit designations	1
Roads with three-digit designations	2
Roads with four-digit designations	3
Roads with five-digit designations	4
Other roads	5

The grade is lowered by 1 (except for one-digit roads) if the following additional circumstances are imposed on a traffic artery: very large traffic volume, defense considerations, fire access, special importance of the object (e.g., border bridge), international agreements.

Evaluation of Durability

The six-grade scale imposed to determine degree of wear of a bridge is as follows:

Description	*Rating*
New object	5
Object in initial service life period	4
Object in normal service life period	3
Object close to exploitation	2
In the end stage of exploitation	1
Exploited	0

Hindrances

A set of hindrances has been introduced especially for those objects that have features besides the dominant ones (technical condition, transportation importance) that make it difficult or even impossible to bring a contractor in (special circumstances associated with the bridge, its location, or work technology). These features call for special treatment of the task that gives the necessary time for the preparation of the environment or a special work regimen.

A four-grade ranking of hindrances on a scale of 2 to 5 has been adopted. The respective intervals are as follows:

Description	*Rating*
No hindrances	2
Extraneous equipment present, traffic restrictions, historical bridge or area	3
Environmental aspects (effect on environment)	4
Necessary bypass or temporary crossing	5

Work Urgency

Work urgency, in the sense of an absolute priority for carrying out work on a bridge, is considered only in the case of a collapse or the continuation of work (value 0). In other cases, its value is neutral and equal to 1.

The effect of ratings of the particular diagnostic features on the acceleration or delay of repairs can be interpreted as follows—the higher the grade, the more the delay:

Description	*Rating*
Technical condition	0–5 (delaying)
Road's technical class	0–5 (delaying)
Durability	0–5 (accelerating)
Work urgency	0–1 (delaying)
Hindrances	2–5 (delaying)

Taxonomic Investigation Method

Taxonomy is a domain of statistical multivariat analysis that deals with theoretical principles and rules of classification, subordination, grouping, and so on, of multifeature objects. The subject of the classification is a set of objects, bridge objects in this case, described by diagnostic features, or arguments.

The division of diagnostic features into stimulants, destimulants, and nominates is characteristic for each multifeature object studied (*14*). A *stimulant* is a variable whose high value is advantageous for a studied object, for example, the rating of the technical condition of a bridge. A *destimulant* is a variable whose high value is disadvantageous for a studied object, for example, a hindrance. A *nominate* is a variable whose value is neutral for a studied object, for example, work urgency in cases other than collapse or continuation of work.

It is possible to consider different variants of diagnostic features depending on the aim and the nature of the investigated problem. The algorithm used is fully universal and open-ended. The method used here will consist of inputting a list of bridges described by vectors of numerical data representing diagnostic features, or arguments for doing repairs on these objects. The output will be a list of bridges ordered according to the urgency of repair.

After the primary goals of the study were determined, a set of bridges was created and arguments for repairs to be carried out on each of the studied objects were specified. It should be emphasized that a proper selection of these features allows one to determine the essential characteristics of the investigated phenomenon and to eliminate quantities that carry too incidental or too detailed information.

The next step was the formation of a matrix of information about the studied bridges, that is, a set of features ascribed to these objects, which was then reduced by statistical procedures (coefficient of linear correlation) to a set of diagnostic features. Next the diagnostic features were subjected to standardization; that is, they were made comparable and freed from designation. The standardized features have two properties: their average value is equal to zero and the standard deviation equals 1.

The next stage is the construction of a taxonomic measure of development. It is based on the concept of the so-called *standard of development*, which is an ideal object with standardized coordinates. When this measure is constructed, it is assumed that all diagnostic features are treated as equally important.

A taxonomic measure of development is the extent of the deviation of the considered bridge from the established standard of development. The above measure is interpreted as follows: the smaller the value that it assumes, the better the condition of the considered bridge, that is, the further it is down on the list of repairs to be made.

To fulfill the postulate that a higher value of this measure indicates a better condition of the bridge, the so-called *relative taxonomic measure of development* was constructed. This measure reveals that the less a value differs from 1, the less different is the level of the studied bridge from the standard object, that is, the further it is down the list of repairs to be carried out.

In this case, the stimulants are the rating of the object's technical condition, the category of road, and evaluation of the bridge's degree of wear. Hindrances are destimulants, whereas work urgency, not in the sense of collapse or work continuation, constitutes a nominate.

The algorithm constructed using the method of taxonomic investigation generates a list of bridges ordered according to the urgency of repair work, whereas the amount of funding allocated to a given DODP shows what the possibilities are of doing repairs in this region, which results in a basic plan of maintenance.

Algorithm of Modules BUM and RKOM at Regional Level: Construction of Maintenance Plan (*13*)

Bridge maintenance in Poland has only a few sources of funding. Bridges on national highways are financed from the central budget, which is distributed on the national level by the GDDP. This process is supported by module BUM, which on this level divides optimally the financial means for 17 DODPs.

Optimization of funds distribution at the central level is based on the method of linear programming. The important factors in this algorithm are the following: bridges' area, average bridge condition, replacement value, year of bridge construction, kind of material. Every year, the program Bridge Data Books (KPOM) groups all factors separately for every DODP. The task of the DODP is to prepare a proposed maintenance plan for each bridge with a list of all work on all bridges, which is generated by the program Basic Inspection Data Form Editor (KPP). This list is subject to approval by the GDDP after budget allocation.

The yearly construction of a maintenance work plan by each DODP is facilitated by the optimization procedures contained in modules BUM and RKOM. The algorithm for the operation of these modules at the regional level is presented in Figure 2.

The task of module BUM at this level is, by linking the anticipated range and scope of work (determined during basic and detailed inspections) with a catalog of work and a catalog of prices, to determine the amount of expenditure on current maintenance (routine work) for bridges and to qualify work as repair rehabilitation.

Module RKOM at the regional level compiles a list of bridges needing repairs, orders it according to urgency, and checks if there is a necessity for modernization. Using the catalogs, it calculates the capital costs for repairs and submitted modernizations.

These operating ranges of the two modules require correlation with the Bridge Work Catalog and the Unit Prices Catalog. This is possible through proper notation-coding of the range and scope of work in program KPP conforming to the specifications of the catalogs.

List of Needed Repairs

Data from inspections contain a list of work to be done on an object in order to restore the service parameters. Therefore, one can say that the material and financial needs in the area of rehabilitation are specified.

The features that describe an object and are essential for its identification and its placement on the priority list are stored in SGM. From now on, the object will be understood by the procedure as a set of diagnostic features necessary for classification plus a list of work to be done. Thus, a list of objects and a list of needs based on these features are obtained. Such a list of needs is subjected to selection to divide it into current maintenance, rehabilitation, and recommended modernization.

The work assigned in the work catalog passes to the group of current maintenance work. The total financial range of work for all bridges in this group gives the total amount for current maintenance in a region, which in turn, when deducted from the amount of the DODP's budget, gives the amount of expenditures on rehabilitation.

The bridges suggested for modernization that are under the management of regional administrations form a list of modernization needs that is subject to a decision procedure depending on the powers of road administration organs. Some objects that did not qualify for modernization remain in the maintenance group.

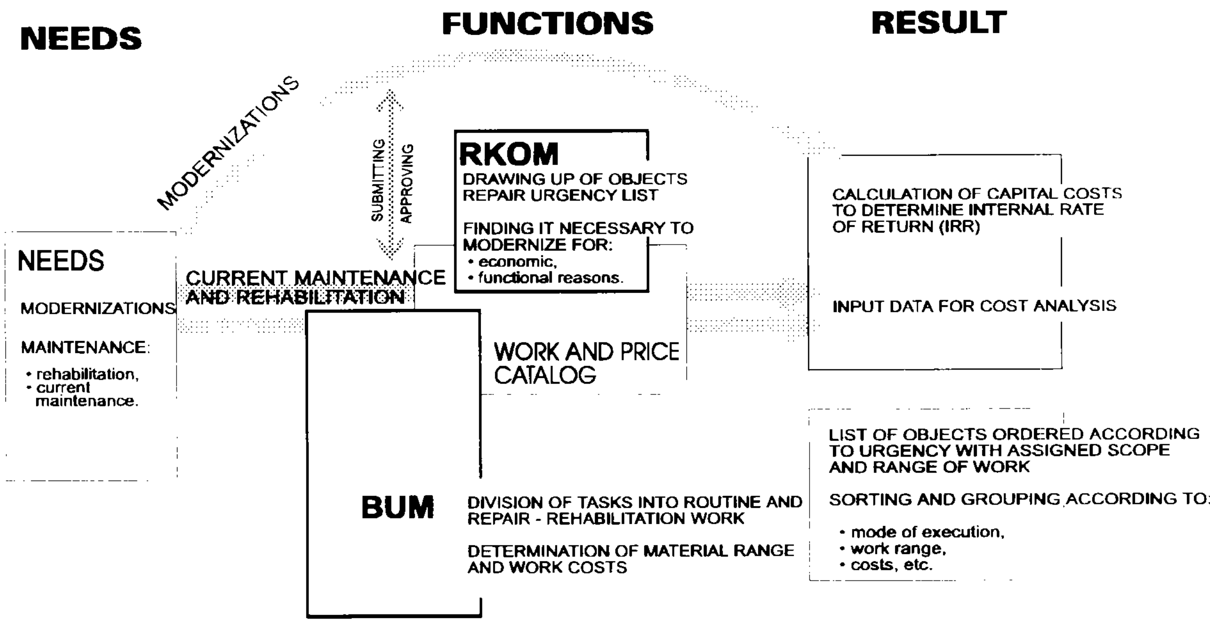

FIGURE 2 Construction of maintenance plan: location of BUM and RKOM procedures.

List of Priority

The ordering of needs, that is, the drawing up of a list of bridge objects in the order of repair work priority, is done by the taxonomic method. The method's diagnostic features are based on the bridge's technical condition, the class of road, evaluation of the bridge's degree of wear, expected hindrances, and mode of work urgency.

The outcome of this procedure is a list of bridges ordered according to the priority of repair work:

Bridge 1_description_identifier_work list_work cost
: : :
: : :
bridge n_description_identifier_work list_work cost

The budget at the disposal of a DODP compared with the generated list presents the possibilities of carrying out rehabilitations in the region and forms a basis for the construction of a yearly plan of maintenance.

Analysis of List or Maintenance Plan

The indication of bridge priority constitutes valuable information that aids the decision process in the drawing up of yearly plans of maintenance. Since the possession of information that ties the balanced and ordered work with the budget only by regional level administration would be too much of a simplification, access to the generated list of work has been provided at the level of individual bridges.

The described procedures allows one, to the above extent, to group and order bridges freely according to the range and scope of work and the road's number, as well as making it possible, for example, to select a group of damages that are mostly responsible for the lowering of the technical condition rating of a bridge.

Frequently, the needs exceed the budgetary means. Therefore, the obtained list of bridges ordered according to repair or rehabilitation urgency should be verified and corrected at the Bridges Division of the DODP, where a planner can "manually" control the generated list of work urgency when drawing up a plan of maintenance. In legitimate cases, the position of a bridge on the list may be changed and the scope or the range of the foreseen work widened or narrowed. Each such change will result in automatic generation of a verified list of priority. Finally, the list of bridge work and the appropriate costs must be approved by the General Directorate of Public Roads.

Final Remarks

The algorithms presented form a basis for handling planning at the regional level. The proposed solutions take into account the prospective directions in which the Bridge Management System in Poland will develop.

The algorithms created include the evaluation of bridge durability and technical condition to the fullest possible extent. Moreover, the optimization procedures developed use the taxonomic method, the universality of which has been verified in economic practice. In this case, an additional advantage of the application of this method is the possibility of bringing in, depending on the specificity of bridge management in a given region, new evaluation factors that will make possible a more comprehensive analysis of the distribution of funds for bridge maintenance.

Finally, it should be noted that, depending on the object of management (size of fixed assets), the described optimization procedure can be used optionally also at the lower level of management, the road management units (ZDs).

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